

#### LA-UR-18-28253

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Title: Enhanced Capabilities for Subcritical Experiments (ECSE): Portfolio

Overview

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Intended for: Overview Presentation P/T Colloquium

Issued: 2019-03-11 (rev.1)





# ENHANCED CAPABILITIES FOR SUBCRITICAL EXPERIMENTS (ECSE): PORTFOLIO OVERVIEW

Dave Funk

P/T Colloquium









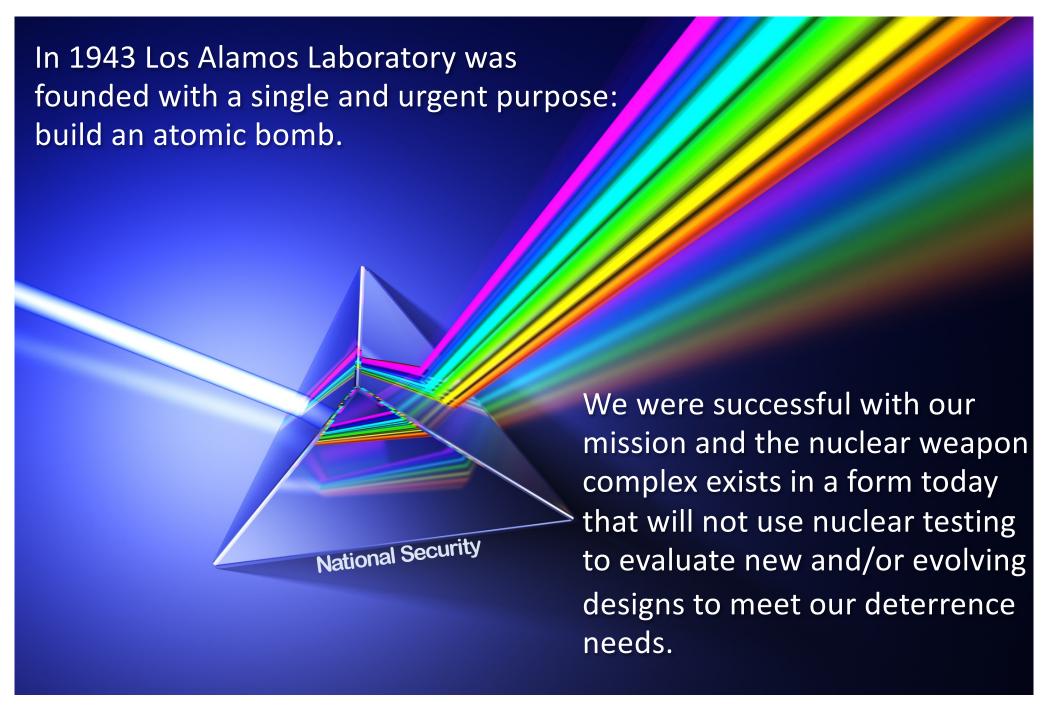


#### **Discussion Topics**

- Mission Need
- Enhanced Capabilities for Subcritical Experiments (ECSE): Two Capital Projects
- U1a Complex Enhancements Project (UCEP)
- Advanced Sources and Detectors (ASD) Project
- Neutron Diagnosed Subcritical Experiments
- Entombment
- Timeline and Integration
- Conclusions











### The Laboratories, Test Site, Production Capabilities, and People, are the heart of our deterrent

### National Laboratories and Test Site

#### **Production Complex**



Los Alamos National Laboratory



Lawrence Livermore National Laboratory



**Pantex Plant** 



**Kansas City Plant** 



Sandia National Laboratories



Nevada National Security Site



Y-12 National Security Complex



Savannah River Site





### LANL is *the* design laboratory for the majority of the Nation's on-alert deterrent

W76
W88
W80
B61
B83
W78
US Navy
US Air Force

- Our deterrence is required as part of our Nuclear Posture
- Changes to the deterrent are expected over time, due to aging, manufacturing methods, and design philosophies.
- A capability gap exists to enable certification of these changes, which involves the evaluation of plutonium response, and the gap will be closed with the ECSE portfolio.











### Modern Stockpile Stewardship: Modeling and simulation, experimentation and surveillance



Stockpile stewardship today



Dual-Axis Radiographic Hydrotest facility (DARHT)

ASD

\*\*Scorpius

**Nuclear material facilities** 

Supercomputing



### **Enhanced Capabilities for Subcritical Experiments: Urgency of Mission Need**

- ECSE is critical to the certification and assessment of the current and future stockpile.
- By adding world-class diagnostics to the U1a facility in Nevada the only place in the nation where we can couple plutonium with high explosives we close an important capability gap.

#### There is no true surrogate for plutonium.

- The U.S. is the only major nuclear power without the capability for latetime radiography of plutonium experiments.
- ECSE will provide new capabilities (ASD Radiography and Neutron Diagnosed Subcritical Experiments (NDSE)) to assess aging and manufacturing effects on the stockpile.
- ECSE will provide vital data supporting future stockpile options.





#### Nuclear performance depends on the way plutonium implodes



**Early time implosion** 

Primary nuclear explosion

HE detonation





**SURROGATES** 

ECSE's Radiographic and NDSE measurements will fill a critical gap in experimental capabilities: the ability to measure plutonium in the final stages of primary implosion





#### **ECSE Portfolio Overview**

#### CD-0 approved in September 2014

- UCEP for infrastructure Line Item Two subprojects DOE O
   413
- ASD for radiographic system (Scorpius) MIE out of Program -DOE O 413
- NDSE R&D for neutron diagnostic Program
- Entombment Drift for "spent" SCEs Program

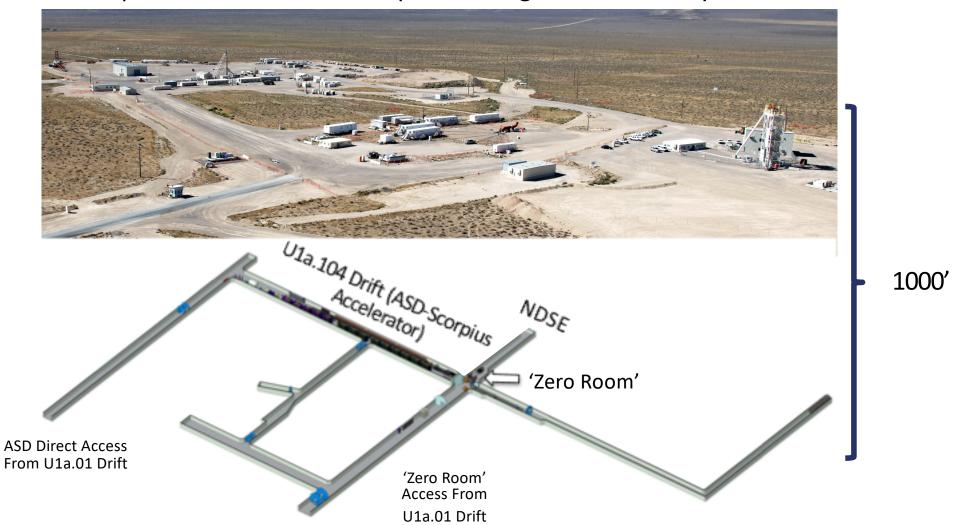
The investment for ECSE is planned over a 10 year period.





#### **U1a Complex Enhancements Project (UCEP)**

- UCEP for infrastructure Line Item DOE O 413.3B
  - Improvements to U1a to setup the underground Laboratory





### The U1a Complex has been an underground laboratory for decades





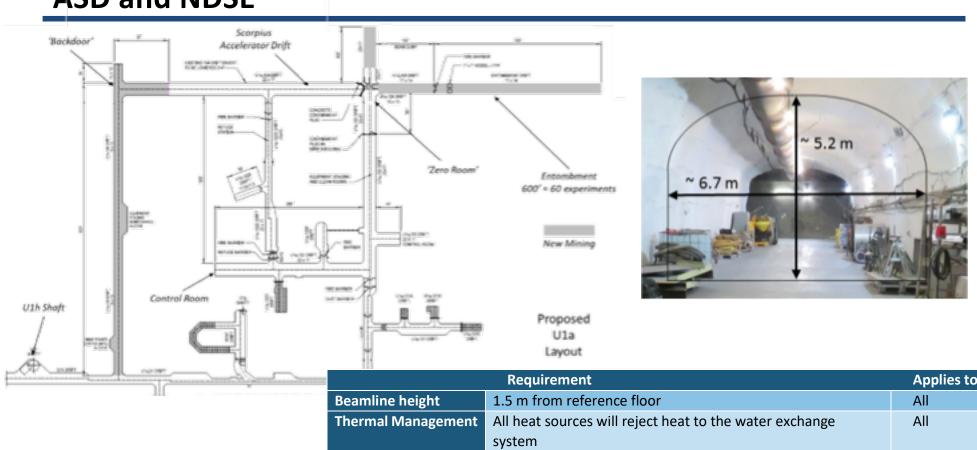
#### **UCEP Project Description**

- UCEP will provide the supporting structures, systems, and components necessary for the deployment of multi-pulsed radiography (ASD/Scorpius) and Neutron Diagnosed Subcritical Experiments (NDSE) technology. Including:
  - Refuge Station Drift
  - Accelerator Drift
  - NDSE Collimator and Detector Alcove
  - Mechanical Equipment drifts
  - Clean rooms
  - Containment Plugs
  - Ventilation, chilled water, and electric power system upgrades
  - Distributed utilities
- UCEP's Tailoring Strategy is to divide the project into two subprojects:
  - UCEP Subproject 010: ECSE Access and Life Safety Infrastructure
  - UCEP Subproject 020: ECSE Laboratory and Support Infrastructure





### Facility and Operational Requirements are Defined to Support ASD and NDSE



	Applies to	
Beamline height	1.5 m from reference floor	All
Thermal Management	All heat sources will reject heat to the water exchange system	All
Mechanical Alignment	System must be movable and have repeatable alignment consistent with beam transport and imaging requirements	Injector, Accelerator, Downstream
Fit in U1a	All installed hardware must allow for reasonable installation, maintenance, troubleshooting, and replacement. Must also allow passage of hardware from downstream systems. All hardware will be sized to fit in the U1h elevator cage (size and mass) and be able to fit through a 2.4m square aperture.	All





### UCEP Subproject 010: ECSE Access and Life Safety Infrastructure Description

- Constructs temporary utilities and ventilation necessary for the mining of new drifts
- Constructs a new U1a.108 Drift, connecting to a new extension of the existing U1a.104 Drift
- Repurposes the existing U1a.102D Drift to serve as a new refuge station



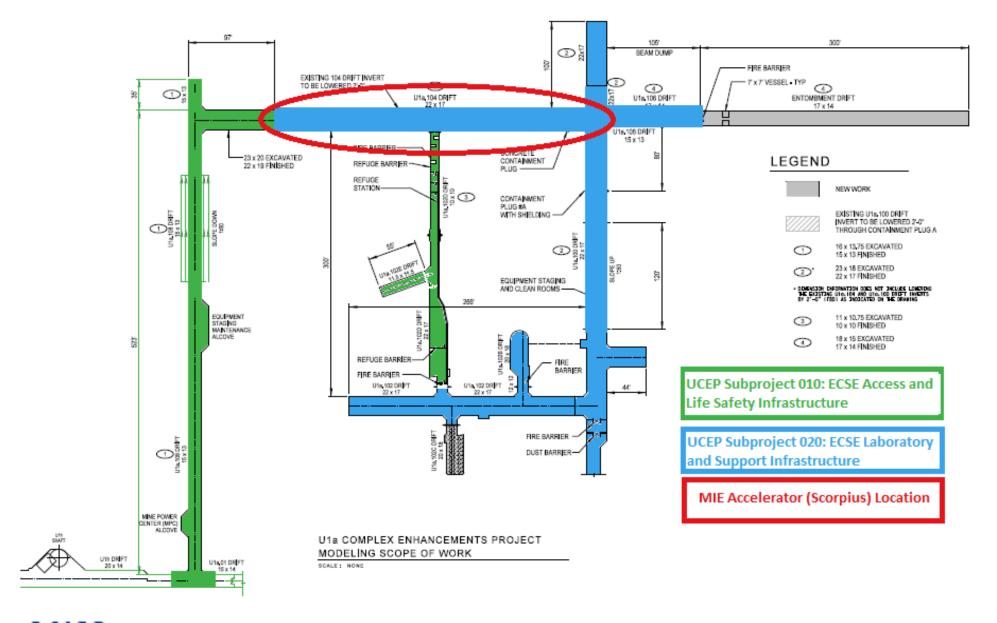
### UCEP Subproject 020: ECSE Laboratory and Support Infrastructure Description

- Constructs the infrastructure and interfaces for ASD/Scorpius and future NDSE technology
- Constructs one plug in the U1a.104 drift and one barrier in the U1a.100 drift
- Constructs all standard utilities
- Constructs mechanical systems associated with ASD/Scorpius
- Installs reinforced inverts in the U1a.104 and new Zero Room
- Constructs diagnostic clean rooms, control rooms, and office/work spaces
- Constructs a new zero room capable of executing subcritical experiments in 6 foot vessels
- Installs fire detection and alarm throughout the ECSE area and fire suppression in selected areas if required





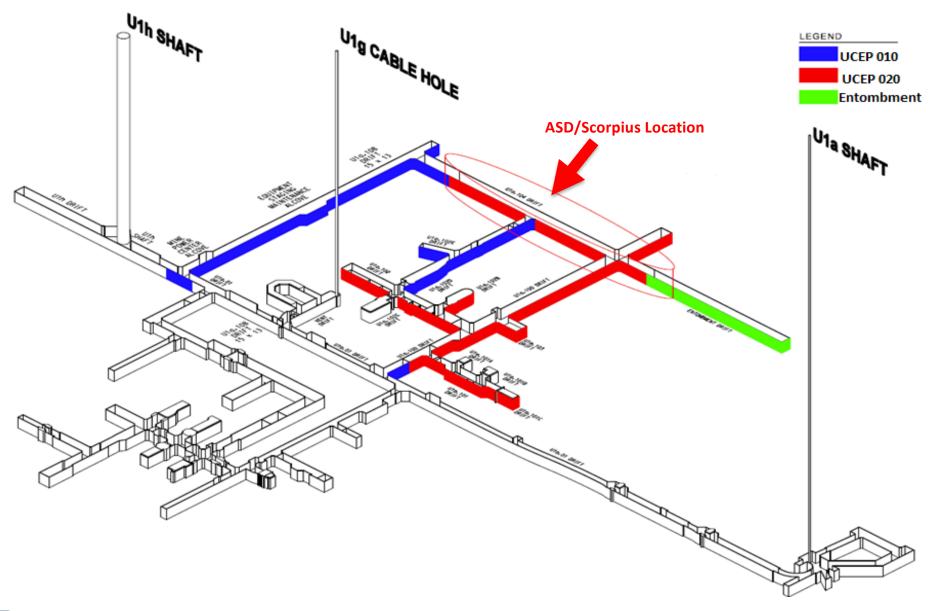
#### **UCEP Preliminary Design Sketch**







#### **U1a Complex - ECSE Area**





#### **UCEP Subproject Status / Major Milestones**

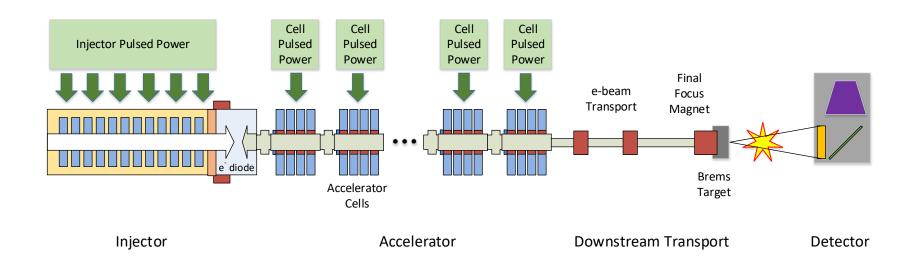
- UCEP Received CD-1 Approval for combined Subproject 010 and Subproject 020 August 2017
- UCEP Subproject 010 CD-2/3 approval is anticipated in February 2019 – final design and start of construction
- UCEP Subproject 020 geotechnical modeling and mining design is currently being performed by Jacobs EngineeringSubproject 020 CD-2/3 approval is scheduled for October 2020 – final design and start of construction
- Beneficial Occupancy (BO) for installation of ASD Scorpius is scheduled for 4Q FY22





#### **Advanced Sources and Detectors (ASD) Project**

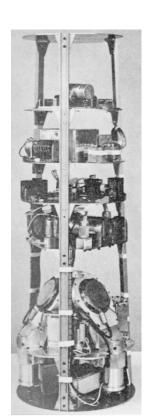
 ASD is the radiographic system – Major Item of Equipment (MIE)



#### Scorpius is the radiographic diagnostic

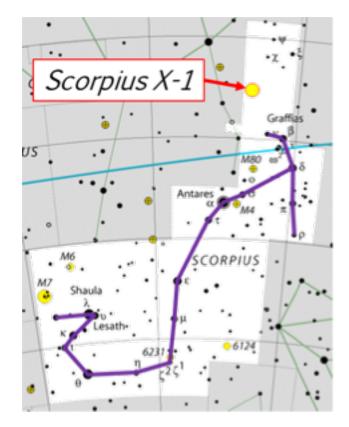


#### Why Scorpius?



Instrument Package that discovered Scorpius X-1.

- Following in the tradition of Cygnus, the ASD System is named for a cosmic x-ray source.
  - Scorpius X-1 is the brightest extrasolar x-ray source visible from the earth.
  - Initially discovered (accidentally) in 1962 by Riccardo Giaconni, it led to the establishment of x-ray astronomy and a Nobel Prize for Giaconni in 2002.
  - It is also appropriate that the scorpion is a underground dwelling desert creature.

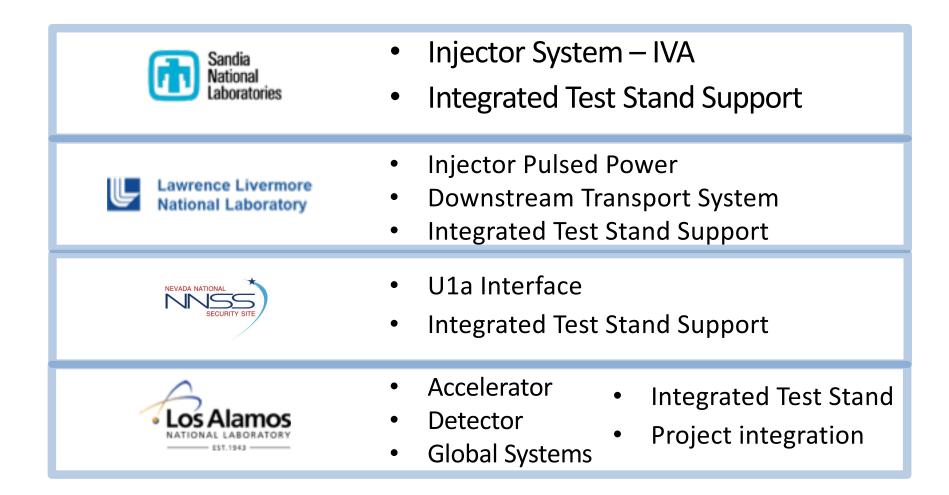


Approximate location of Scorpius X-1 in Scorpius Constellation



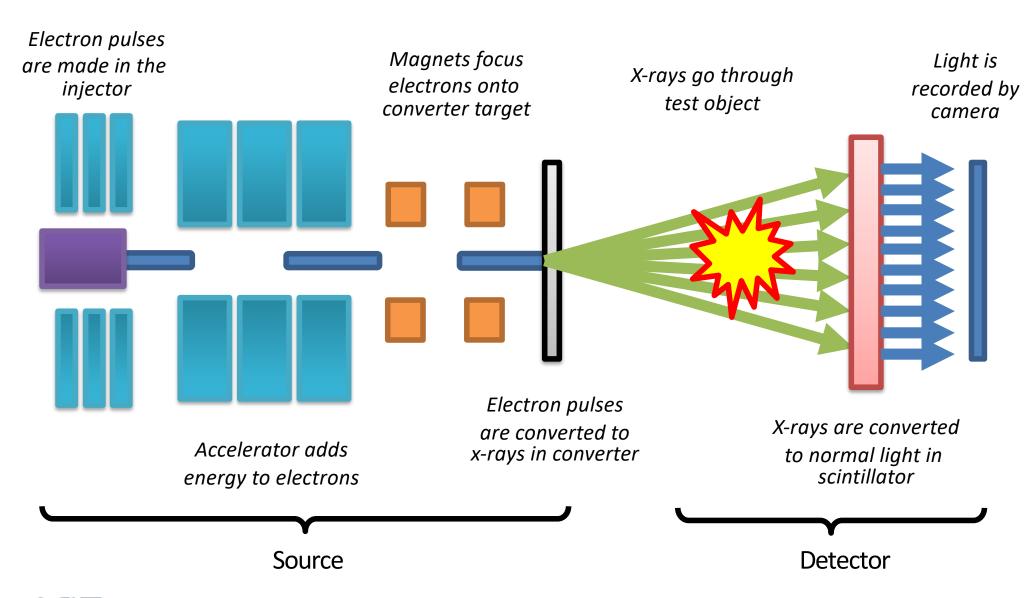


### The ASD Project Collaboration capitalizes on the strengths of the partner laboratories





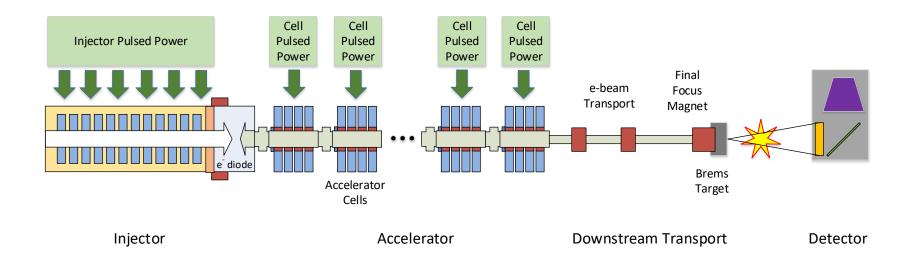
#### A radiographic system consists of a source and a detector





#### **ASD-Scorpius Key System Requirements**

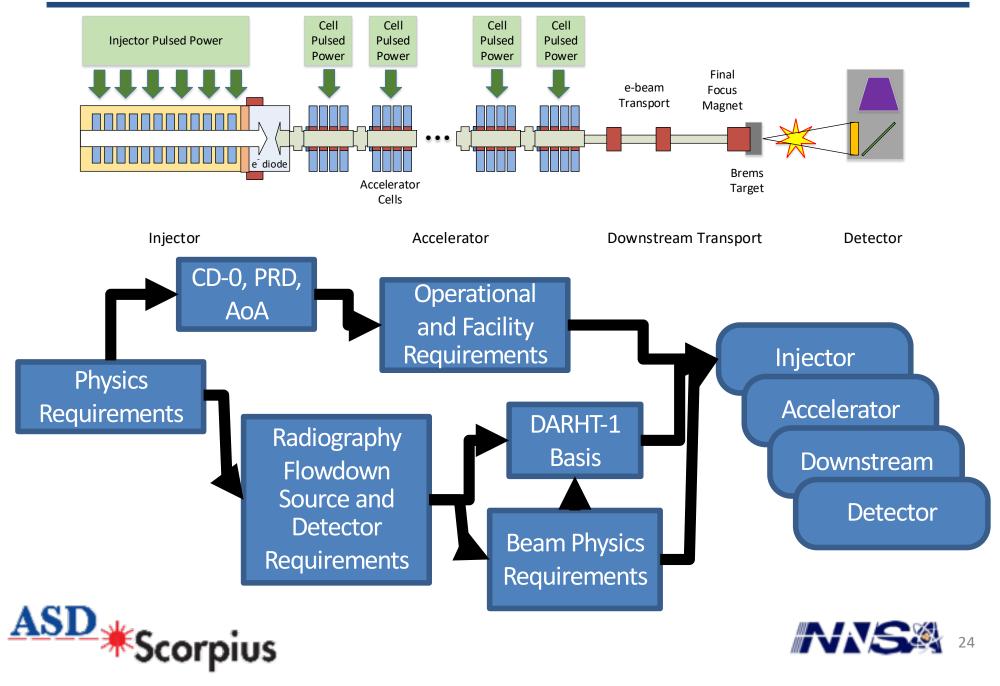
- Four-pulse, Single-axis Radiographic System
  - Includes both the source and the detector
  - Image quality equal to DARHT-1
  - Pulse separation as short as 200 ns (center to center)
  - Installed at the U1a Complex at NNSS





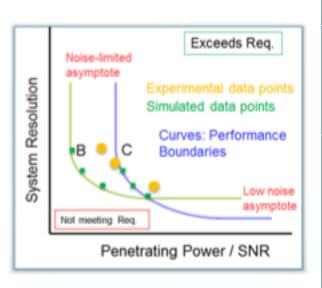


### A detailed requirements flowdown sets the primary system requirements



#### **Radiographic Analysis and Requirements**

- Detector needs to equal or exceed DARHT-1 system
  - For thicker objects, an anti-scatter "Bucky" grid is necessary, but may reduce capability for thinner objects.
- Source Needs to equal or exceed DARHT-1 capability



	Radiographic System Parameters			
	Equal to (or exceeding) DARHT-1			
Darht-1 Source Dose ≥ 550R @1m				
	Spot Size < 2.76 mm 50% MTF (LANL definition; DARHT-1 Reference)			
	DARHT-1 LIA parameters:			
	Electron Beam Energy = 19.5 MeV			
	Electron Beam Current = 1.8 kA Electron Beam Pulse Width = 83ns FWHM			
DARHT-1 Detector	RHT-1 Detector   Detector Resolution >> Source Limiting Resolution			
	Detector Sensitivity ~ a few mR downstream of the object			
	DARHT-1 Detector Parameters:			
	≥40% Zero Frequency Detective Quantum Efficiency (DQE(0))			
	≤2µR Noise Equivalent Sensitivity to MeV photons			
	≤1.0 mm Scintillator Pitch			
	≥4X CCD Sampling at Scintillator Plane			
	≥ ~4X Radiographic Magnification			
	≥1,000:1 CCD Frame Isolation			
	≥16,000:1 Dynamic Range			
	≥10:1 x-ray Scatter Rejection (Bucky Grid; needs to be removable)			



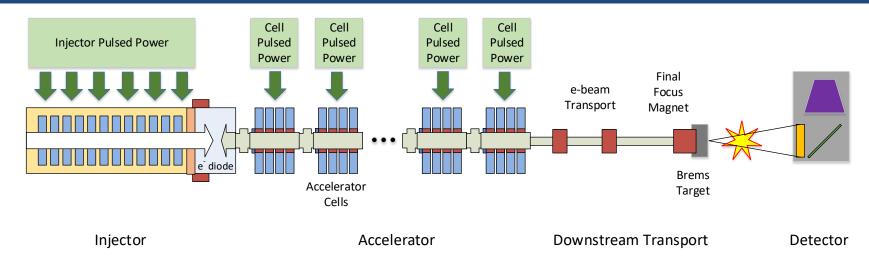


### Beam Physics Requirements are based on meeting DARHT-1 Source Performance

 Nine different transport and instability issues were evaluated and well-defined requirements for each system were established

Beam Transport Issue	Mitigating Measure	System Requirement	Applies to
Emittance Growth	Matched beam tune for small size Steering dipoles to center beam	Dipoles in Cells (10 G on axis) ±1% Bz reproducibility	Accelerator
Beam Breakup (BBU)	Accelerating gap and cavity design Transport Magnetic field	Cell Zperp < DARHT-1 Mod2a Bz > 2 kG on axis ±1%	Accelerator
Image Displacement Instability (IDI)	Transport Magnetic field	Cell Bz > 0.2 kG	Accelerator
Corkscrew motion	Tight alignment tolerance Quiet pulsed-power Corrector dipoles in cells	Cell Alignment < 0.2 mm RMS dE/E < 5% RMS (~ ±7%) Dipoles in Cells (10 G on axis)	Accelerator Injector
Ion Hose Instability	High throughput distributed vacuum pumping Transport Magnetic Field	Vacuum < 200 nTorr	Accelerator, Downstream
Resistive Wall Instability	High-conductivity Beam Tubing Transport Magnetic Field	High σ (Al or Cu) Tubing Bz > 2 kG on axis ±1%	Accelerator, Downstream
Diocotron Instability	Diode design to produce convex profile High energy diode	Non-hollow beam Injector>1.5 MV	Injector
Final Focus Chromatic Aberration	Minimal beam energy variation	Total beam energy variation at entrance to FF magnet < 2% rms	Injector Accelerator Downstream
Parametric Envelope Instability	High- energy matched-beam tune	None	All
*Scorpius			

#### **Conceptual Design Overview**



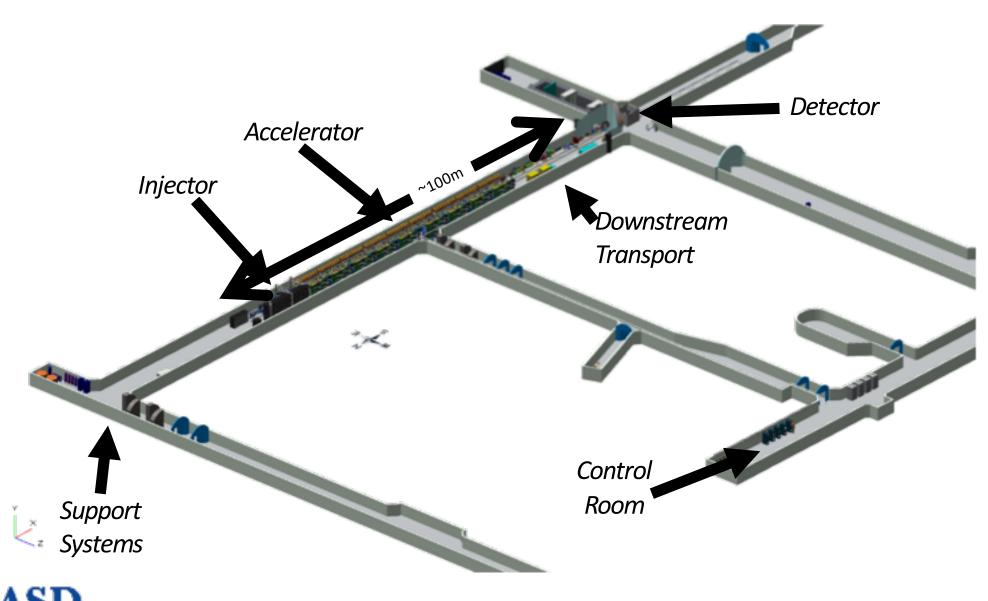
- Injector Four-pulse, 2 MV, 2 kA, 85ns
  - Vacuum IVA with thermionic cathode driven completely by solid state pulsers
- Accelerator 9, 2MeV Blocks, Four-pulse, 250 kV cells
  - Based on DARHT-1 cell (multi-pulse performance validated) and 2x2 SPFL pulsed power architecture
- Downstream Transport
  - 4 to 1 dose control,
- Detector
  - Based on DARHT-2 system, updated camera development, removable anti-scatter "Bucky" grid





#### Scorpius has been designed to fit in the U1a Complex

\*Scorpius



### We have developed a Work Breakdown Structure for the Project that is aligned with the accelerator work scope

Primary Technical Systems

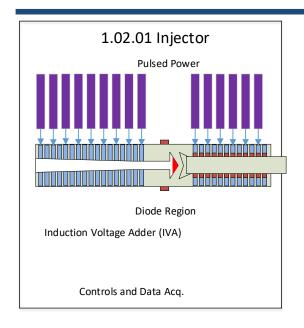
- 1. Advanced Sources and Detectors
  - 1.01 Project Management
  - 1.02 Radiographic System
    - 1.02.01 Injector
    - 1.02.02 Accelerator
    - 1.02.03 Downstream Transport
    - 1.02.04 Detector
    - 1.02.05 Global Systems
    - 1.02.06 U1a Facility Interface
    - 1.02.07 Integrated Test Stand
    - 1.02.08 Staging and Support Facility
    - 1.02.99 Technical Management
  - 1.03 Systems Engineering and Requirements
  - 1.04 System Integration at U1a
  - 1.05 System Testing and Qualification at U1a

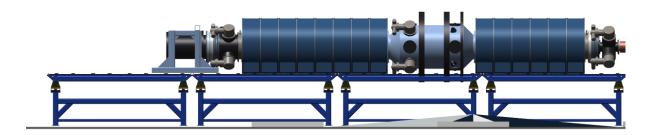
Installation/Test Activities



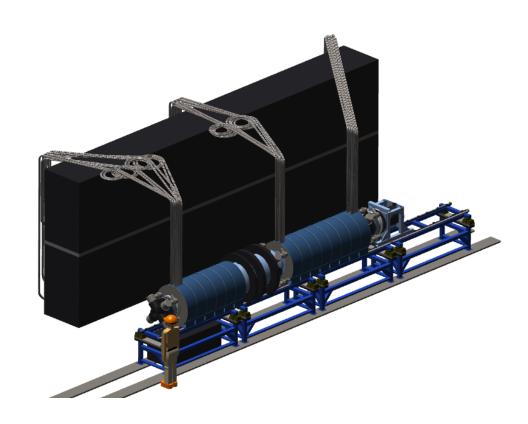


#### 1.02.01 Injector – the source of the beam



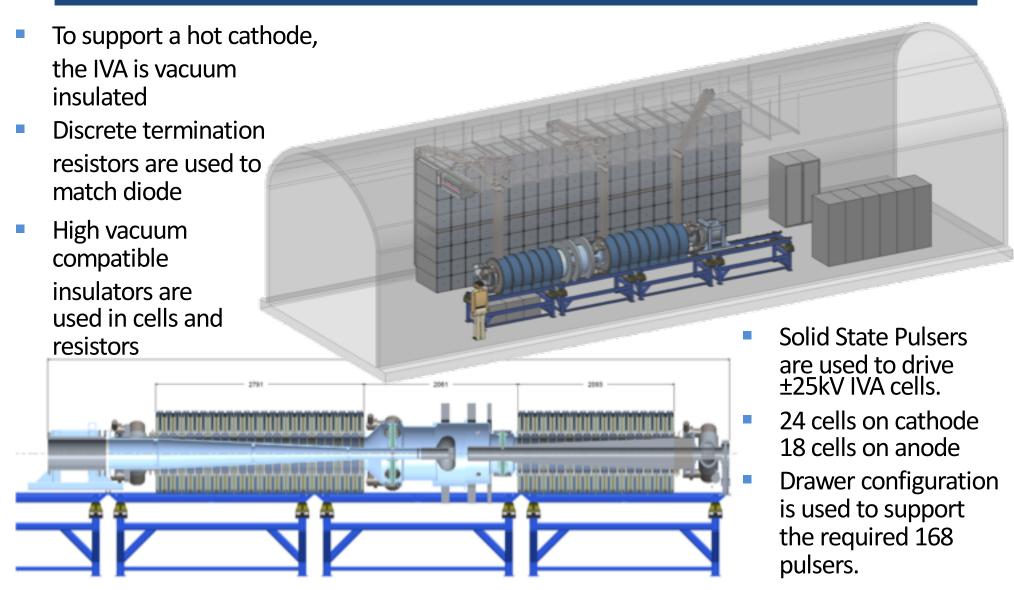


- The injector generates the initial high-energy pulses of electrons.
- There are very tight requirements on the voltage and current of the electron pulse
- Lead Josh Leckbee, Sandia



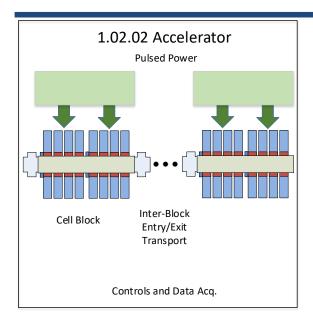


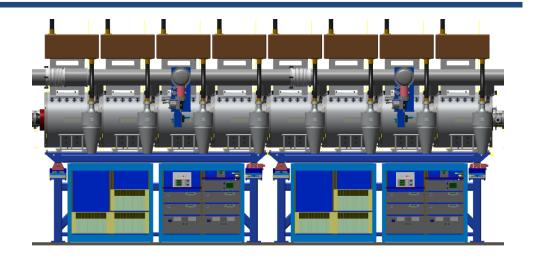
## The Injector uses a Thermionic Cathode which places stringent requirements on vacuum and heat management



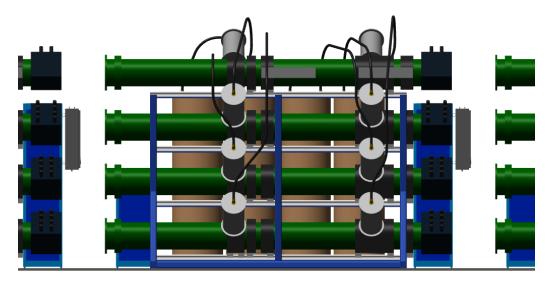


#### 1.02.02 Accelerator – increases the electron beam energy



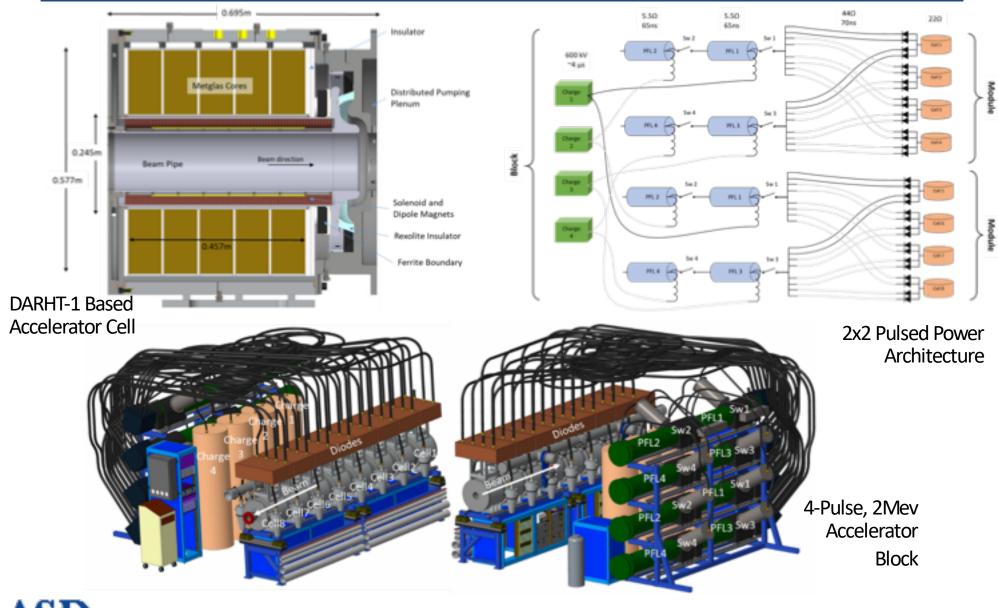


- The accelerator adds the necessary energy to the electrons.
- There are a large number of beam transport issues that have to be handled through careful system design and testing
- Lead Greg Dale, LANL





## Accelerator design has been significantly matured due to recent experimental validation





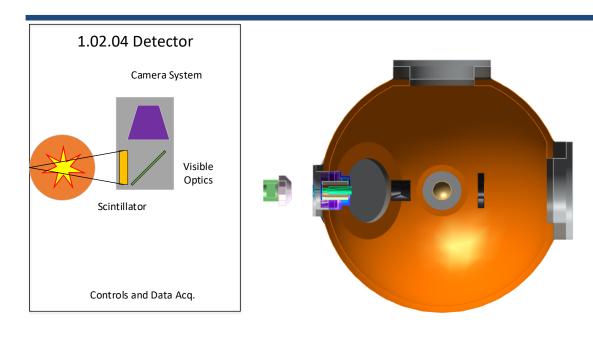
### 1.02.03 Downstream Transport – converts the electron beam to x-rays – based on DARHT Axis II

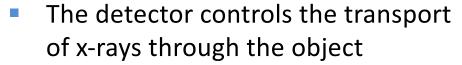


- The DST conditions the beam for conversion to x-rays
- Converts the electrons to x-rays
- Manages debris and provides safe operating modes
- Lead Jennifer Ellsworth, LLNL

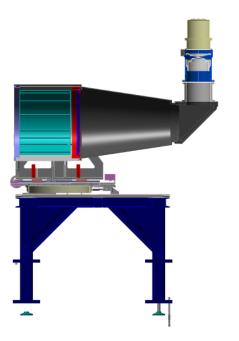


#### 1.02.04 Detector – converts transmitted x-rays into an image





- Converts the x-rays to visible light
- Captures and records that light
- Lead Jacob Mendez, LANL

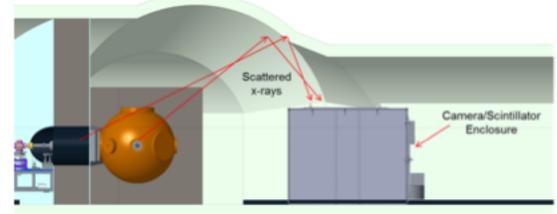






#### The Detector system, based on DARHT-2 is fairly mature, but work is needed

- The primary challenges for an advanced, high-speed, detector system is the industrial base to support it.
  - There are only two thick, large-area, pixelated, LSO scintillators in use today; DARHT-1 and DARHT-2. The capability to manufacture a similar system needs to be re-invigorated.
  - Similarly, a 4-frame, 200ns camera does not exist. DARHT is making an investment with MIT-LL to build an 8-frame, 250ns camera (200ns may be possible).
    - Investment in a 4-frame, 200ns camera system is planned
- The U1a location also provides a new challenge, additional scattered radiation sources.
  - Significant effort in MCNP models is needed to understand the U1a environment and required shielding
  - Neutrons may be a big deal







#### 1.02.05 Global Systems – connect all the other systems together

Global Controls and
Data Acq. Vacuum System Power and Grounding Fluid and Gas Systems Alignment Systems Maintenance Tooling Safety Systems

1.02.05 Global Systems





#### **Other WBS Elements**

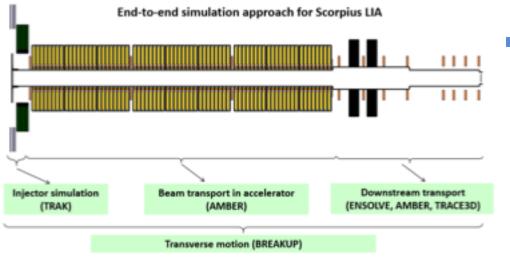
- 1.02.06 U1a Facility Interface
  - Develops and maintains interface documents and, where necessary, hardware to interface with UCEP
  - Lead Dr. Al Meidinger, NNSS
- 1.02.07 Integrated Test Stand (ITS)
  - Infrastructure and support to provide above ground system integration and testing
- 1.02.08 Staging and Support Facility
  - Infrastructure and support for hardware acceptance and configuration at NNSS prior to installation in U1a
- 1.02.99 Technical Management
- 1.04 System Integration at U1a
  - Resources and systems to install and integrate hardware in U1a
- 1.05 System Testing and Validation at U1a
  - Resources and systems to test and validate systems and integration in U1a





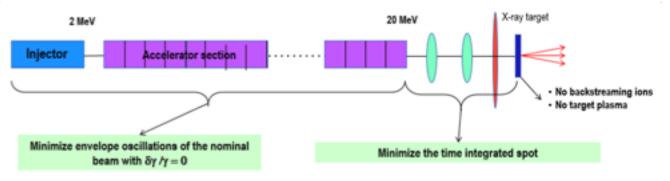
## **End to End Beam Transport Simulations show a viable Conceptual Design**

 A suite of modeling tools has been used to calculate the beam transport from the injector to the Bremsstrahlung target.



 Validated modeling codes are used in the appropriate regions. Handoff relies on expertise to ensure proper conditions are met.

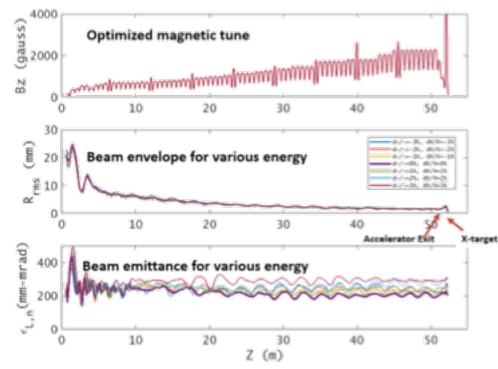
Beam energy
 variations are
 modeled as linear
 ramps, but transport
 is set for ideal case





#### End to End simulations indicate good spot size for energy variations up to ~ ±2%

- These results are consistent with DARHT-1 experience
- Most of the increase in spot size is due to chromatic aberration in the final focus magnet.
- Beam target interactions will likely be a dominate factor.



Energy Spread dY/Y	Energy Spread dV/V	E <sub>n,l</sub> (Lapostolle)	50% MTF	Spot Variation	Dose Variation
Injector	Accelerator	mm-mrad	mm		
±0%	±0%	206	0.648	0	0
±1%	±1%	225	0.655	+1.1%	-0.3%
±2%	±2%	241	0.659	+1.7%	-0.6%
±3%	±3%	267	0.689	+6.2%	-1.2%



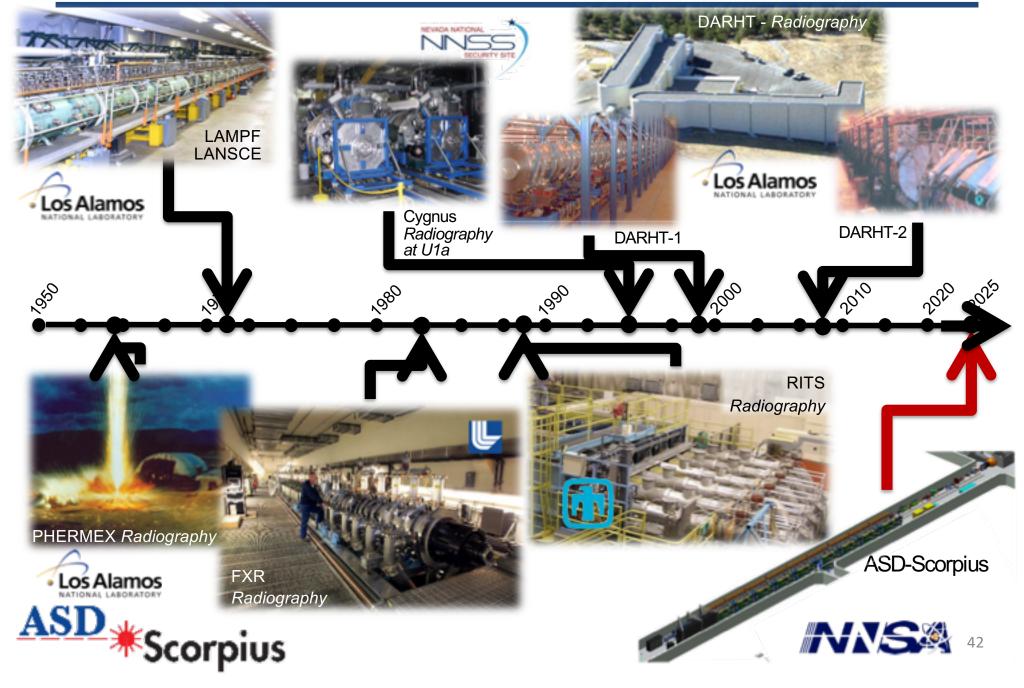


#### A Technology Maturation Plan (TMP) has been developed that extends the system maturity from TRL-4 to TRL-6

- The TMP is a living document that is being updated as technical issues are addressed and/or discovered.
- For CD-1, TRL-4 is appropriate
- The Project is using TRL-6 as the appropriate maturity level for CD-2/3.
- Technology Maturation is occurring primarily for:
  - Multi-pulse Thermionic Cathode
  - Solid State Pulsers
  - Diode Isolation
  - Series Pulse Forming Water Lines
  - Scorpius Accelerator Cell
- The system will be assembled and tested locally (Integrated Test Stand at MPF-365)



## The ASD-Scorpius team has broad experience on similar systems in the Complex



#### **Neutron Diagnosed Subcritical Experiments (NDSE) Program**

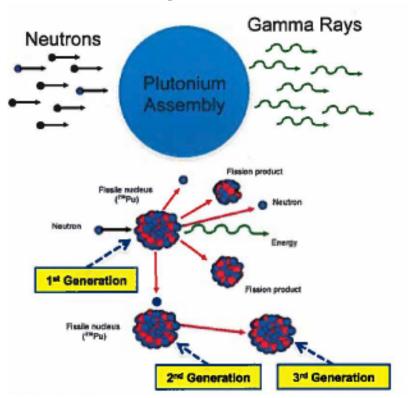
- NDSEs quantify the neutron multiplication ("chain reaction") that is the fundamental mechanism that generates energy in nuclear weapons.
- Neutron multiplication is extremely sensitive to plutonium compressibility, and understanding the compressibility of plutonium under the conditions encountered in a nuclear weapon primary will be a key factor in our developing Life-Extension Program (LEP) options (including pit reuse), and establishing the safety/surety characteristics for the future stockpile.

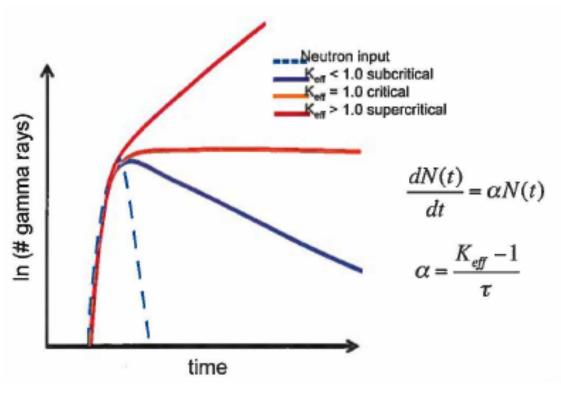
Wallin, B.K., R.B. Webster, M. Herrmann, J. Gatling, "Mission Need Statement and Program Requirements for Subcritical Experiments", LLNL-TR-650015, 17 Feb 2014.



## NDSE aims to constrain the peak reactivity of subcritical experiments by measuring the fission decay rate

- The NDSE concept induces plutonium fission via a short burst of externally generated neutrons and measures the decay of the resulting prompt fission gamma rays.
  - This is analogous to reaction history measurements in underground testing.

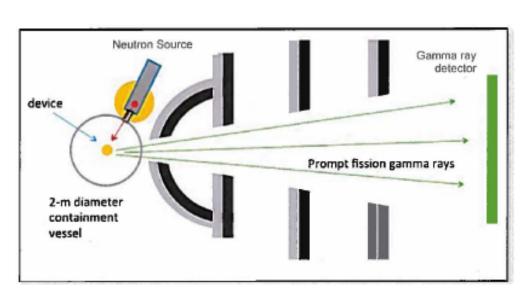


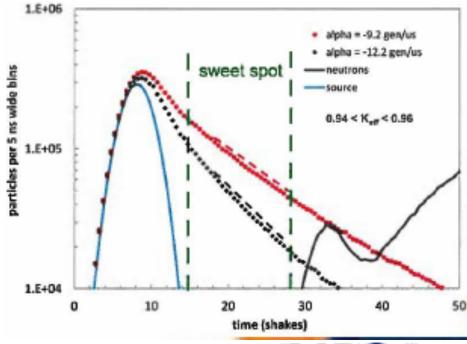




#### Key elements are required to make an NDSE measurement on a subcritical Pu experiment

- Neutron source: A short (<60ns) burst of sufficient (> 2 x 10<sup>7</sup>) 1st generation fissions initiated via an external neutron source at peak plutonium compression
- Gamma ray detector: Gamma ray detector minimally affected by neutrons and scattered gamma rays
- Background reduction: Collimation and shielding that controls neutron and gamma scattering to reduce noise levels
- Reliability: Low neutron timing uncertainty (< ±75ns) and sufficient neutron yield</p>



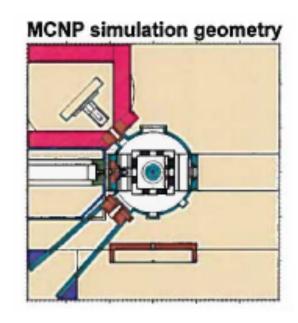




### Dense Plasma Focus (DPF) and photofission based neutron sources are the most promising technologies for NDSE

- Both DPF and photofission NDSE sources are being experimentally evaluated
  - Photofission: better pulse shape and reliability, more 1st generation fission
  - DPF: compact, relatively inexpensive, n and y background suppression via not as challenging, may not be compatible with simultaneous radiography
- Cygnus-based photoneutron, Godiva, and laser ion-acceleration neutron sources are also being considered, via 'paper studies'

Objects K <sub>eff</sub>	Scaled SCE 0.93	Scaled SCE 0.93	Bare Pu 0.96	Bare Pu 0.96
Source	LIA 19.6 MeV	DPF	LIA 19.6 MeV	DPF
1st Generation Fissions in Pit	5.8E8	3.4E7	7.8E8	3.9E6
1st Generation Fissions in Case	5.6E7	untallied	- NA -	- NA -
(n,n') in pit	4.8E9	untallied	1.2E10	2E7
(n,γ) in pit	4.6E8	6.2E7	8.9E8	2.0E7
(n,fissions) in pit	8.8E9	1.2E9	2.3E10	5.1E8



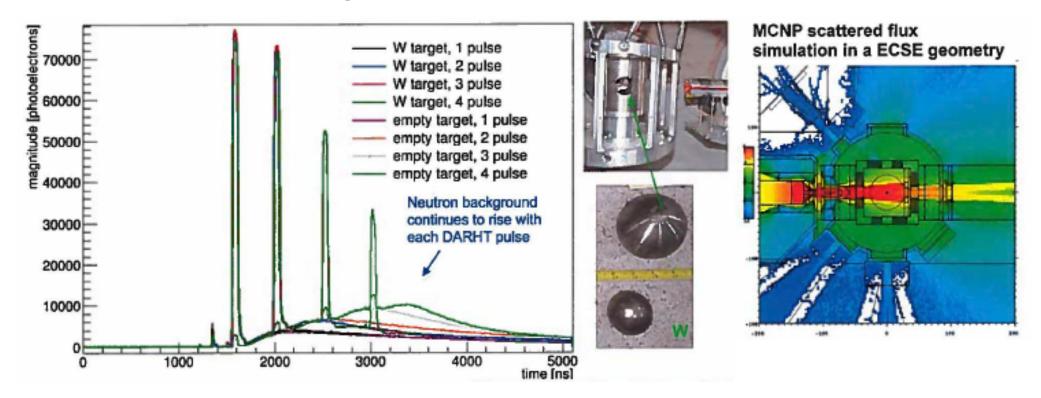


**Static** 



#### Currently, the focus is on NDSE-ECSE integration and selecting a preferred source of neutrons

- UCEP facility infrastructure to support NDSE
- Understanding how to control the scattering and backgrounds when co-located with Scorpius
- DARHT scattering measurements have been made



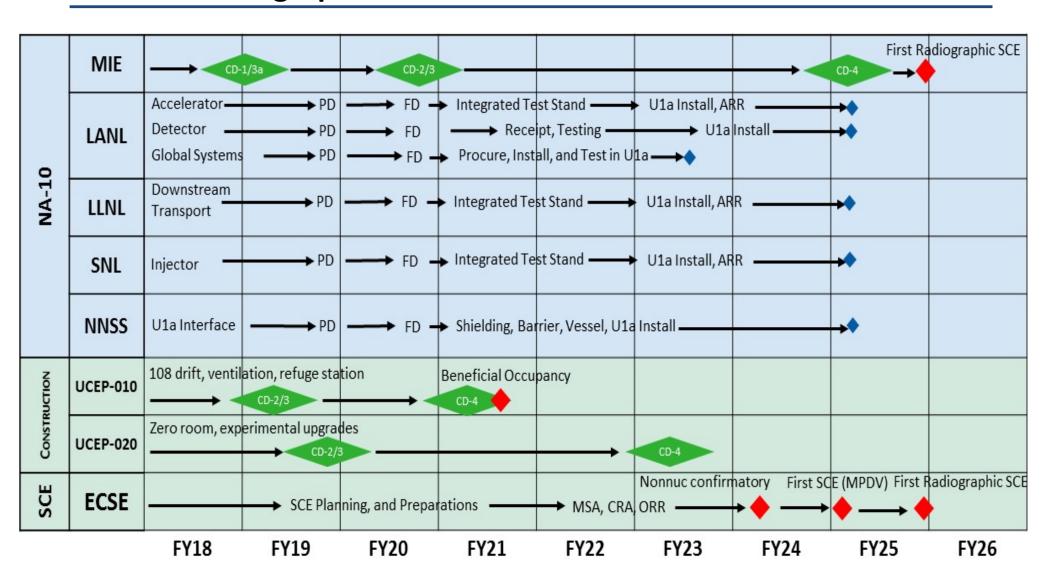


#### Entombment Drift Project Description: The location used to place expended SCEs

- Entombment is a separate programmatically funded project to be executed concurrently with UCEP
- The entombment drift will be either a 600' x 10' x 10' drift or a 300' x 14' x 17' drift for entombing expended vessels used for SCEs
  - The drift size will be determined pending completion of criticality evaluation.
  - \$16.9M has been budgeted for entombment
- Entombment final design completion is scheduled for Jan 2019
- Entombment start of mining is scheduled for FY19
- Entombment completion is scheduled for FY21



## Our high level Project Milestone Schedule supports execution of the first radiographic SCE in FY2025







#### ECSE – a new set of capabilities to enhance our understanding of the dynamic behavior of plutonium

- UCEP for infrastructure Line Item Two subprojects DOE O
   413
- ASD for radiographic system (Scorpius) MIE out of Program -DOE O 413
- NDSE R&D for neutron diagnostic Program
- Entombment Drift for "spent" SCEs Program

# New capabilities, new insight, better understanding, a stronger deterrent



